

STRONG DOUBLE AND TRIPLE HIGGS PRODUCTION AT CLIC

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Work in progress with
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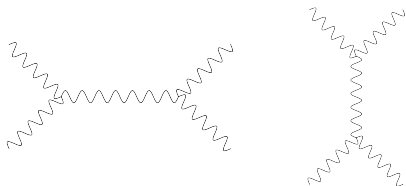
OUTLINE

- 1 MOTIVATION
- 2 PHENOMENOLOGY
- 3 CONCLUSION AND OUTLOOK

PERTURBATIVE UNITARITY VIOLATION IN THE SM

- Scattering of longitudinally polarized W :

$$\mathcal{L} = \frac{v^2}{4} \text{Tr} \left[(D_\mu \Sigma)^\dagger (D_\mu \Sigma) \right] \quad \Sigma(x) = e^{i\frac{\sigma^a}{v} \chi^a}$$



$$\mathcal{A}(W_L W_L \rightarrow W_L W_L) \sim \frac{s+t}{v^2}$$

- Amplitude grows with energy
 - \Rightarrow violates perturbative unitarity at $\Lambda \sim 2\text{TeV}$
 - \Rightarrow expect new degrees of freedom

HIGGS AS A COMPOSITE NAMBU-GOLDSTONE-BOSON

Weak Dynamics:
Higgs Boson



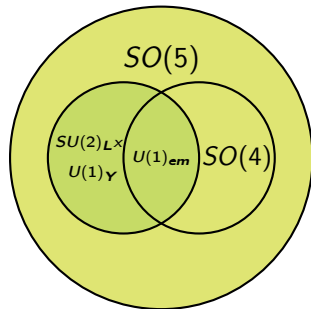
Strong Dynamics:
Non-perturbative Interactions



Interpolation: **Strongly interacting light Higgs**

[Giudice, Grojean, Pomarol, Rattazzi 07]

- Higgs - bound state of strongly interacting sector
- Minimal Coset:
 $SO(5)/SO(4)$
 \Rightarrow 4 NG-bosons
3 eaten, 1 Higgs
- Breaking scale f



ANOMALOUS HIGGS COUPLINGS

- Higgs potential at one-loop in weak gauge coupling \Rightarrow
 $\langle H \rangle = v$ dynamic

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - V(h) + \left(m_W^2 W_\mu^+ W^{\mu-} + \frac{m_Z^2}{2} Z_\mu Z^\mu \right) \left[1 + 2a \frac{h}{v} + b \frac{h^2}{v^2} + b_3 \frac{h^3}{v^3} + \dots \right]$$

$$V(h) = \frac{1}{2} m_h^2 h^2 + d_3 \left(\frac{m_h^2}{2v} \right) h^3 + \dots$$

- Couplings in terms of $\xi = \frac{v^2}{f^2} = \frac{\text{weak scale}^2}{\text{strong scale}^2}$

$$a = \sqrt{1 - \xi} \quad b = 1 - 2\xi \quad b_3 = -\frac{4}{3}\xi \sqrt{1 - \xi}$$

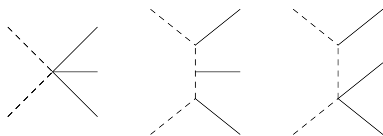
- SM: $\xi = 0 \Rightarrow a = b = 1, b_3 = 0$

DISCRETE SYMMETRY IN SYMMETRIC COSET MODEL

- Symmetric coset \Rightarrow discrete symmetry between NG bosons:

$$\pi^{\hat{a}} \rightarrow -\pi^{\hat{a}}$$

- Process with odd number of NG-bosons forbidden
- W_L scattering:



$$\begin{aligned} \mathcal{A}(\pi\pi \rightarrow hhh) &= \frac{is}{v^3} (4ab - 4a^3 - 3b_3) \\ &= 0 \end{aligned}$$

- Distinct feature to distinguish symmetric and asymmetric coset

Polarisation	Amplitude for	
	symmetric coset	asymmetric coset
$LL \rightarrow hhh$	$\frac{g^2 v}{f^2}$	$\frac{E^2 v}{f^4}$

PROBING THE COMPOSITE HIGGS

- Directly: probe heavy resonances
- Indirectly: Enhanced production rate of two and three Higgs bosons

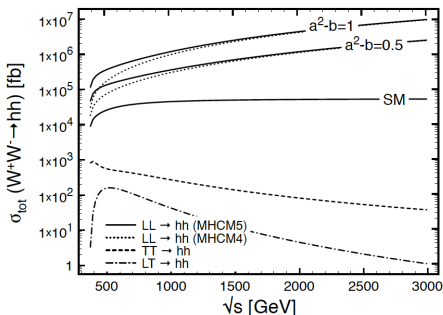
$$\mathcal{L} = \frac{v^2}{4} \text{Tr} \left[(D_\mu \Sigma)^\dagger (D_\mu \Sigma) \right] \left[1 + 2a \frac{h}{v} + b \frac{h^2}{v^2} + b_3 \frac{h^3}{v^3} + \dots \right]$$

- Determine anomalous Higgs couplings
- Single Higgs Production: sensitive to a

DOUBLE HIGGS PRODUCTION AT LHC

- Process: $q\bar{q} \rightarrow hhq'\bar{q}'$
[Contino, Grojean, Moretti, Piccinini, Rattazzi '10]
- Amplitude growing with energy

$$\mathcal{A}(\pi\pi \rightarrow hh) = \frac{s}{v^2} (b - a^2)$$



- Extremely challenging due to large QCD background

DOUBLE HIGGS PRODUCTION AT CLIC

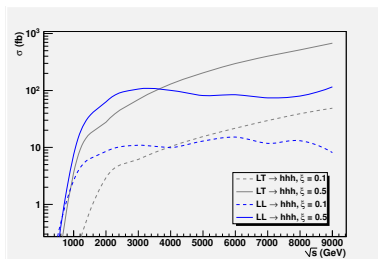
- CLIC - **C**ompact **L**inear **C**ollider
 - e^+e^- linear collider
 - 33 km
 - design center of mass energy: 3, 5 TeV
- Process: $e^+e^- \rightarrow W^+W^-\nu\bar{\nu} \rightarrow hh\nu\bar{\nu}$
- Assume negligible SM background, full Higgs reconstruction
- Sensitive to quadratic and trilinear coupling: precision $\sim 1\%$
 - \Rightarrow sensitive to ξ
 - \Rightarrow sensitive to compositeness scale

TRIPLE HIGGS PRODUCTION AT CLIC

- **Symmetric coset:** $\sigma \sim \mathcal{O}(1)ab$

- $LL \rightarrow hhh$ cancels
- dominant contribution: $LT \rightarrow hhh$

$$\sigma(W_L W_T \rightarrow hhh) = \frac{c_{HG}^2 g^2}{12288\pi^3 f^4} s \log \frac{s}{m_W^2} + \mathcal{O}(s)$$



- **Asymmetric coset or non- σ model:** $\sigma \sim \mathcal{O}(100)ab$

- dominant contribution $LL \rightarrow hhh$

CONCLUSION AND OUTLOOK

- CLIC - unique machine to probe strong and composite nature of the Higgs
 - Double Higgs production: sensitive to anomalous couplings
⇒ compositeness scale
 - Triple Higgs production: distinguish between symmetric and asymmetric coset
⇒ insight on underlying dynamics
- Still to do:
 - finish analysis
 - build CLIC!